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	Engineer and Design CONTROLLED LOW STRENGTH MATERIAL WITH COAL-COMBUSTION ASH AND OTHER RECYCLED MATERIALS	
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CEMP-ET

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
Washington, DC 20314-1000

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Technical Letter
No. 1110-3-496

15 December 1998

Engineering and Design
CONTROLLED LOW STRENGTH MATERIAL
WITH COAL-COMBUSTION ASH AND OTHER RECYCLED MATERIALS

1. Purpose. This letter provides information and guidance for design and construction of controlled low strength material (CLSM). CLSM has many applications but has been primarily used as a flowable, self-compacting fill in place of a compacted fill. An example specification containing provisions for using fly ash and other recycled materials in the CLSM mix is also provided.
2. Applicability. This letter is applicable to all HQUSACE elements and USACE commands having military construction and design responsibility.
3. References. ER 1110-345-100.
4. Distribution. Approved for public release; distribution is unlimited.
5. Background.
 - a. CLSM is a self-compacting, cementitious material used primarily as a backfill in lieu of compacted fill. Often called flowable-fill, CLSM should flow easily during construction and gain sufficient strength to be walked on and buried within a day. CLSM is especially popular as a excavatable material for backfilling trenches and other hard-to-compact locations. To allow for future excavation most current CLSM applications require unconfined compressive strengths of 50 to 300 psi. Waste materials can sometimes be recycled by their use in CLSM mixtures. Waste materials that may be suitable as aggregates for CLSM include bottom ash produced in the coal combustion process, discarded foundry sand, and reclaimed crushed concrete. In all cases, the characteristics of the non-standard material should be determined, and the suitability of the material should be tested in a CLSM mixture to determine whether it meets specified requirements.
 - b. This ETL provides guidance and design recommendations for the use of CLSM with coal-combustion ash and other recycled materials. The information provided is for use of CLSM for backfill, structural fill, insulating and isolation fill, pavement base and conduit and culvert bedding.

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6. Action. The enclosed guidance and design recommendations should be used by the Army for the design and construction of flowable fills.

7. Implementation. This letter will have routine application for all future military projects as defined in paragraph 8c, ER 1110-345-100.

FOR THE DIRECTOR OF MILITARY PROGRAMS:



DWIGHT A. BERANEK, P.E.
Chief, Engineering and Construction Division
Directorate of Military Programs

1 Appendix

APPENDIX A

CONTROLLED LOW STRENGTH MATERIAL WITH COAL-COMBUSTION ASH AND OTHER RECYCLED MATERIALS

1. Purpose. This Engineer Technical Letter (ETL) provides background and an example specification for controlled low strength material (CLSM). CLSM has many applications but has been primarily used as a flowable, self-compacting fill in place of a compacted fill. The example specification contains provisions for using fly ash, bottom ash, and other recycled materials within the CLSM mix.

2. Basic Documents and References. To provide a state-of-the-practice specification for use by Corps of Engineers and Army practitioners, this ETL is based on a recently-updated specification for CLSM by the State of New York Department of Transportation (NYSDOT), which is performance-based and incorporates lessons learned from earlier field experiences. NYSDOT has indicated that industry concurs with its requirements, which, while limited to a specific region of the US, demonstrates the acceptance of the specification among both suppliers and owner representatives. This ETL is also based on ACI 229R-94, "Controlled Low Strength Materials (CLSM)." In addition, ASTM standard test methods have been developed for CLSM. These and other references are listed in the Appendix.

3. Background. Extensive background and guidance on controlled low strength material is given in ACI report 229R-94. That report has been used liberally in the preparation of this section.

a. Material description. As described by ACI 229R-94, CLSM is a self-compacting, cementitious material used primarily as a backfill in lieu of compacted fill. Often called flowable-fill, it should flow easily in construction and gain sufficient strength to be walked on and buried within a day. CLSM is especially popular as an excavatable material for backfilling trenches and other hard-to-compact locations. To allow for future excavation most current CLSM applications require unconfined compressive strengths of 50 to 300 psi. However, CLSM is defined in a broader sense by ACI 116R, "Cement and Concrete Terminology," as materials that result in a compressive strength of 1200 psi or less. The upper limit of 1200 psi allows use of this material for applications where future excavation is unlikely such as structural fill under buildings.

Most CLSM mixes are currently designed to incorporate marketable components such as water, cement, fly ash, and natural sand. However, recent research and experience shows that currently non-marketable or non-standard components such as non-ASTM-conforming fly ash and coal-combustion bottom ash may be used as long as the materials have been tested and found to satisfy the intended application. The example specification in this ETL contains provisions for using fly ash and recycled aggregate, including bottom ash.

While CLSM is a cementitious material that has much in common with concrete, it is not

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considered a type of low strength concrete, but rather as an alternative to compacted fill. Indeed, long-term compressive strengths of 50 to 300 psi are very low when compared to concrete. However, in terms of allowable bearing pressure, which is a common criterion for measuring the capacity of a soil to support a load, 50 to 100 psi strength is equivalent to a well-compacted fill. Although CLSM generally costs more per cubic yard than most soil or granular backfill materials, its many advantages often result in lower in-place costs.

Generally CLSM mixtures are not designed to resist freezing and thawing, abrasive or erosive forces, or aggressive chemicals.

b. Applicability. The primary application of CLSM is as a backfill or structural fill in lieu of compacted soil. Because CLSM needs no compacting and can be designed to be very fluid, it is ideal for use in tight or restricted-access areas where placing and compacting fill is difficult. Specific application areas include backfills, structural fills, insulating and isolation fills, pavement bases, and conduit and culvert bedding.

Backfills CLSM can be readily placed into a trench, hole or other cavity. Compacting is not required, hence the trench width or size of excavation may be reduced. When backfilling against retaining walls, consideration should be given to the lateral pressures exerted on the wall by flowable CLSM. Where the lateral fluid pressure may be a concern, CLSM may be placed in layers with each layer allowed to harden prior to placing the next layer.

Structural fills CLSM may be used for foundation support. Compressive strengths may vary from 100 to 1200 psi depending upon application. In the case of weak soil it can distribute a structure's load over a greater area. For uneven or non-uniform subgrades under foundation footings and slabs, CLSM can provide a uniform and level surface. Compressive strengths will vary depending upon project requirements. Because of its strength, CLSM may reduce the required thickness or strength requirements of the slab.

Insulating and isolation fills Low density CLSM material made with preformed foam is generally used for these applications.

Pavement bases CLSM mixtures may be used for pavement bases, subbases and subgrades. The mixture may be placed directly from the mixer onto the subgrade between existing curbs. Good drainage is required when using CLSM mixtures in pavement construction. Freezing and thawing damage could result in poor durability if the base material is frozen when saturated with water. A wearing surface is required over CLSM since it has relatively poor wear resistance properties.

Conduit and culvert bedding CLSM provides an excellent bedding material for pipe, electrical, telephone and other types of conduits, and culverts. The flowable characteristic of the material allows the CLSM to fill voids beneath the pipe or culvert and provide uniform support. Bedding can also provide erosion resistance by preventing water from getting between the pipe and bedding, eroding the support. Encasing the entire conduit in CLSM also serves to protect the conduit from future damage. If the area around the conduit is being excavated at a later date, the obvious material change in CLSM versus the surrounding soil or conventional granular backfill would be recognized by the excavating crew, alerting them to the existence of the conduit.

Coloring agents have been used in mixtures to help identify the presence of CLSM.

c. Mix Components. Conventional CLSM mixtures usually consist of water, portland cement, fly ash or other similar by-products, and fine or coarse aggregates or both. Some mixtures consist of water, portland cement and fly ash only. Special low density CLSM mixtures consist of portland cement, water and preformed foam.

Although materials used in CLSM mixtures may meet ASTM or other standard requirements, the use of standardized materials is not always necessary. Selection of materials should be based on availability, cost, specific application and the necessary characteristics of the mixture including flowability, strength, excavatability, density, etc.

Cement provides the cohesion and strength for CLSM mixtures. Increasing cement content while maintaining other components equal will normally increase strength and reduce hardening time. For most applications, Type I or Type II portland cement conforming to ASTM C 150 is normally used. Fly ash is sometimes used to improve flowability. The quantity of fly ash used will be determined by availability and flowability requirements of the mix. Its use may also increase strength and reduce bleeding, shrinkage and permeability. Most fly ashes used conform to either Class F or Class C as described in ASTM C 618. However, fly ashes not conforming to ASTM C 618 may be used. In all cases, whether or not fly ashes conform to ASTM C 618 specifications, trial mixes should be prepared to determine whether the mixture will meet the specified requirements.

Water serves as a lubricant to provide high flowability characteristics and promote consolidation of the materials. Water that is acceptable for concrete mixtures is acceptable for CLSM mixtures. ASTM C 94 on Ready Mixed Concrete provides additional information on water quality requirements.

Air-entraining chemical admixtures can be valuable constituents for the manufacture of CLSM. Air takes up space and improves flowability, assisting performance while enhancing economy. It can also be used to enhance insulating characteristics and provide for reduced density, and may also be used as a means of limiting the maximum strength of CLSM. Although chemical admixtures have been used successfully in CLSM mixtures, pretesting should be performed to determine acceptability. Also, air-entraining agents may not be cost effective unless they are needed to satisfy specific requirements.

Aggregates are often the major constituent of a CLSM mixture. The type, grading and shape of aggregates can affect the physical properties such as flowability and compressive strength. Granular excavation materials with somewhat lower quality properties than concrete aggregate are a potential source of CLSM materials, and should be considered. However, variations of the physical properties of the mix components will have a significant effect on the mix performance. Silty sands with up to 20 percent fines (minus #200 sieve) have proven satisfactory. Also, soils with wide variations in grading have been shown to be effective. However, soils with clayey fines have exhibited problems.

Non-standard materials, which may be available and more economical, can also be used in CLSM mixtures depending upon project requirements. Examples of non-standard materials that

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may be suitable as aggregates for CLSM include bottom ash produced in the coal combustion process, discarded foundry sand, and reclaimed crushed concrete. In all cases, the characteristics of the non-standard material should be determined, and the suitability of the material should be tested in a CLSM mixture to determine whether it meets specified requirements. In certain cases, environmental regulations may require prequalification of the raw material or CLSM mixture or both, prior to use.

d. Properties. The properties of CLSM cross the boundaries between soils and concrete. CLSM is manufactured from materials similar to those used to produce concrete and is placed from equipment in a fashion similar to that of concrete. But in-service CLSM exhibits characteristic properties of soils. The properties of CLSM are affected by the constituents of the mix and the proportions of the ingredients in the mix.

Flowability Flowability is the property that makes CLSM unique as a fill material. It enables the materials to be self-leveling, to flow into and readily fill a void, and be self-compacting without the need for conventional placing and compacting equipment. Flowability can be varied from very stiff to very fluid depending upon requirements. A major consideration in using highly flowable CLSM is the hydrostatic pressure it exerts. Where fluid pressure is a concern, CLSM may be placed in lifts, with each lift being allowed to harden before placement of the next lift.

Segregation Separation of constituents in the mixture can occur at very high levels of flowability when the flowability is primarily produced by the addition of water. With proper proportioning, a high degree of flowability can be attained without segregation. For highly flowable CLSM without segregation, adequate fines are required to provide suitable cohesiveness. Fly ash generally accounts for these fines, although silty or other noncohesive fines up to 20 percent of total aggregate have been used.

Subsidence Subsidence deals with the reduction in volume of CLSM as it releases its water and entrapped air through consolidation of the mixture. Most of the subsidence occurs during placement and the degree of subsidence is dependent upon the quantity of free water released. Typically, subsidence of 1/8 to 1/4 inches per foot of depth is common. This amount is generally found with mixtures of high water content. Mixtures of lower water content undergo little or no subsidence and cylinder specimens taken for strength evaluation have experienced no measurable change in height from the time of casting to the time of testing.

Hardening time Hardening time is the approximate period of time required for CLSM to go from the plastic state to a hardened state with sufficient strength to support the weight of a person. When this excess water leaves the mixture, solid particles realign into intimate contact and the mixture becomes rigid. Hardening time is greatly dependent on the type and quantity of cementitious material in the CLSM. Hardening time can be as short as one hour, but generally takes 3 to 5 hours under normal conditions. A load resistance test according to ASTM D 6024 can be used to measure the hardening time or the suitability of loading of the CLSM.

Pumping CLSM can be successfully delivered by conventional concrete pumping equipment. As with concrete, proportioning of the mixture is critical.

Strength and bearing capacity Unconfined compressive strength is a measure of the load

carrying ability of CLSM. A CLSM compressive strength of 50 to 100 psi equates to an allowable bearing capacity of a well-compacted soil. Curing methods specified for concrete are not considered essential for CLSM. Maintaining strengths at a low level is a major objective for projects where later excavation may be required.

Density Unit weight of normal in-place CLSM is in the range of 115-145 lb/ft³, which is greater than most compacted materials. A CLSM mix with only fly ash, cement and water should have a unit weight of 90 to 100 lb/ft³. Lower unit weights can be achieved by using lightweight aggregates, high entrained air contents, and foamed mixes. ASTM D 6023 provides a test method for CLSM unit weight.

Settlement Settlement of compacted fills may occur even when compaction requirements have been met. CLSM does not settle after hardening occurs.

Thermal insulation and conductivity Conventional CLSM mixtures are not considered good insulating materials. Where insulation is desired, the mixture should be proportioned to obtain low density and high porosity. Air entrained conventional mixtures reduce the density and increase the insulating value. Lightweight aggregates, including bottom ash, can be utilized to reduce density. Foamed or cellular mixtures have very low densities and exhibit good insulating properties. Where high thermal conductivity is desired, such as backfill for underground power cables, high density and very low porosity (maximum surface contact area between solid particles) are desirable. As the moisture content and dry density increase, so does the thermal conductivity.

Permeability Permeability of most excavatable CLSM is similar to compacted granular fills. Typical values are in the range of 10^{-4} to 10^{-5} cm/sec. Permeability is increased as cementitious materials are reduced and aggregate contents are increased (particularly above 80 percent).

Shrinkage and cracking Shrinkage and shrinkage cracks do not generally affect the performance of CLSM. Several reports have indicated very little shrinkage occurs with CLSM. Typical linear shrinkage is in the range of 0.02 to 0.05 percent.

Excavatability The ability to excavate CLSM at later ages is an important consideration on many projects. In general, CLSM with a compressive strength of 50 psi or less can be excavated manually. Mechanical equipment such as backhoes are used for compressive strengths of 100 to 200 psi. Mixtures using high quantities of coarse aggregate can be very difficult to remove by hand even at low strengths. Mixtures using fine sand or only fly ash as the aggregate filler may be excavated with a backhoe at strengths on the order of 300 psi. Since CLSM will typically continue to gain strength beyond the conventional 28-day testing period, it is suggested, especially for high cementitious content CLSM, that long term strength tests be conducted to estimate the potential for later-age excavatability. In addition to limiting the cementitious content, entrained air can be used to keep compressive strengths low.

e. **Mix proportions.** Proportioning for CLSM has largely been done by trial and error until mixtures with suitable properties have been achieved. Most specifications available provide a recipe of ingredients that will produce an acceptable material, although some specifications call for performance features and leave proportioning up to the supplier. Currently, where a recipe does not exist, trial mixtures are evaluated to determine how well they meet certain goals for

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strength, flowability, density, etc. Adjustments are then made to achieve the desired properties. Within these specifications cement contents generally range from 50 to 200 lb/yd³, depending upon strength and hardening time requirements. Class F fly ash contents range from none to as high as 2000 lb/yd³ where fly ash serves as the aggregate filler. Class C fly ash is used in quantities of up to 350 lb/yd³. The majority of specifications call for the use of fine aggregate. Coarse aggregate is generally not used in CLSM mixes as often as fine aggregates. When used, however, the coarse aggregate content is approximately equal to the fine aggregate content. More water is used in CLSM than in concrete. Water contents typically range from 325 to 580 lb/yd³ for most CLSM mixes containing aggregate. Water contents will be higher with mixtures using finer aggregates.

f. Mixing, transporting, placing, and quality control. The mixing, transporting and placing of CLSM generally follows methods and procedures given in ACI 304. Whatever methods and procedures are used, the main criteria is that the CLSM be homogeneous and consistent and satisfy the requirements for the purpose intended. CLSM may be mixed by several methods, including central-mixed concrete plants, ready-mixed concrete trucks, and pugmills. Most CLSM mixtures are transported in truck mixers. Agitation of CLSM is required during transportation and waiting time to keep the material in suspension. Under certain circumstances CLSM has been transported short distances in non-agitating equipment such as dump trucks.

CLSM may be placed by chutes, conveyors, buckets, or pumps depending upon the application and its accessibility. Internal vibration or compaction is not required since the CLSM consolidates under its own weight. Although it can be placed year round, CLSM should be protected from freezing until it has hardened. For trench backfill CLSM is usually placed continuously. To contain CLSM when filling long open trenches in stages or open-ended structures such as tunnels, the end points can be bulkheaded with sandbags, earth dams, or stiffer mixtures of CLSM. For pipe bedding, CLSM may have to be placed in lifts to prevent floating the pipe. Each lift should be allowed to harden before continued placement. Other methods of preventing floatation include sand bags placed over the pipe, straps around the pipe anchored into the soil or use of faster setting CLSM placed at strategic locations over the pipe. CLSM is not self-supporting and places a load on the pipe. For large, flexible wall pipes, CLSM should be placed in lifts so that lateral support can develop along the side of the pipe before fresh CLSM is placed over the pipe. Backfilling retaining walls may also require the CLSM be placed in lifts in order to prevent overstressing the wall.

CLSM has effectively been tremied and end dumped directly into the water without significant segregation. In confined areas the CLSM will displace the water to the surface where it can easily be removed. Because of its very fluid consistency, CLSM can flow long distances to fill voids and cavities located in hard-to-reach places. Voids need not be cleaned as the slurry will fill in irregularities and encapsulate any loose materials.

For most projects CLSM is pretested using the actual raw materials to develop a mix design having certain plastic (flowability, consistency, unit weight) and hardened (strength, durability, permeability) characteristics. Following the initial testing program, field testing may consist of

simple visual checks, or it may include consistency measurements or compressive strength tests.

4. Example Performance Specification for 40-300 psi Flowable CLSM.

a. Description. Furnish and place a Controlled Low Strength Material (CLSM) as shown on the plans or as directed by the Engineer-In-Charge, in writing. Provide CLSM containing cement and water. At the option of the contractor or engineer, it may contain fly ash, aggregate (including bottom ash or other recycled material), or chemical admixtures in any proportions such that the final product will meet the strength and flow consistency requirements included in this specification.

b. Materials. Provide materials meeting the following requirements:

Portland Cement, Type I or Type II Meet the requirements of ASTM C 150.

Water Meet the requirements of ASTM C 94.

If utilized, these materials shall meet the following requirements.

Aggregate The gradation of the aggregate shall have 100% passing the 3/4" sieve and a maximum of 20% passing the No. 200 sieve. Recycled aggregate (including bottom ash) for use in this item shall be evaluated for quality and gradation by the engineer. Where necessary, provide the engineer with a copy of documentation issued by the appropriate authorities attesting to its conformance with applicable environmental rules and regulations.

Fly Ash Where necessary, provide the engineer with a copy of documentation issued by appropriate environmental authorities attesting to its conformance with applicable environmental rules and regulations. Use fly ash conforming to the chemical and physical requirements for mineral admixture, Class F listed in ASTM C 618 including Table 2 (except for Footnote A). Waive the loss on ignition requirement. If the strength and flow consistency requirements in this specification are met by the CLSM without ASTM C 618 conformance, this requirement may be waived by the Engineer.

Chemical Admixtures Meet the requirements of ASTM C 494, including high air generators manufactured for CLSM.

Certify that the CLSM has a 28-day compressive strength between 40 psi and 300 psi. Cast and test specimens of CLSM in accordance with ASTM D 5971 and 4832. The number or frequency of test specimens shall be as determined by the Engineer. Specimens shall be delivered to the Engineer for evaluation. The test specimens are for informational purposes and will not be used for project acceptance.

c. Construction details. All equipment for this work shall be subject to approval of the engineer

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at all times.

Mix the materials at a stationary mixing plant. The mixer shall be either a continuous or a batch type plant, designed to accurately proportion either by volume or by weight, so that when the materials are incorporated in the mix, a thorough and uniform mix will result. The mixer shall be capable of providing accurate control, at all times, of the amount of material entering the mixer per time interval. The mixer shall be equipped to mechanically interlock the material feeds, such that the uniformity of the mixture is assured.

The mix may be transported in open haul units when the material is placed within 30 minutes of the end of mixing. Material placed in excess of 30 minutes after the end of mixing shall be transported in a rotating drum unit capable of 2 - 6 rpm.

The engineer will determine the flow consistency of the CLSM according to ASTM D 6103.

The method of placing CLSM shall be as approved by the engineer.

The CLSM shall be accepted on the basis of inspection by the engineer.

d. Method of measurement. Payment for CLSM material will be made for the number of satisfactorily placed cubic yards computed between the payment lines shown on the plans or from payment lines established in writing by the Engineer.

e. Basis of payment. The unit price bid per cubic yard shall include the cost of furnishing all labor, materials and equipment necessary to complete the work.

5. Trial Mix Designs Using Example Performance Specification for 40-300 psi Flowable CLSM.

a. Description. To demonstrate the ability of a contractor to meet the flow consistency and 28-day compressive strength requirements of the Example Performance Specification for 40-300 psi Flowable CLSM, as well as the difficulty and constraints of doing so when using significant amounts of coal-combustion ash and other-than-concrete-aggregate sand as aggregate materials, a batch-plant concrete supplier was contracted to develop CLSM mix designs meeting these requirements using bottom ash, sand, and fly ash as aggregate materials. Additionally, the contractor was directed to follow ASTM Standard Methods 4832, 5971, 6023, and 6103 where appropriate for developing the mix designs and for preparing cylinders for strength tests. Following the spirit of the performance specification—i.e., allowing an experienced and innovative contractor to develop CLSM mixes without specifying excessive detail—there were no other mix design constraints included in the contract.

b. Mix Designs and Strength Results. Mix designs used by the contractor in attempting to meet the 40-300 psi strength range of the Example Performance Specification are listed in the table below. For aggregate the contractor used bottom ash in Mixes 1-8, washed concrete sand or unwashed fill sand (as noted by (w) or (f), respectively) in Mixes 9-16, and sand and fly ash in Mixes 17-24. All mix designs met the flow consistency specification. The contractor chose to use two commercially-available air-entraining agents, DaraFill™ and Darex II™ (DX II™).

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The unit weights and 28-day strengths listed in the table were determined independently from three CLSM cylinders provided by the Contractor. ASTM D 6023 and 4832 were followed. Mixes 6-8, 10, 13-17, 19, 21, and 22 met the compressive strength specification; the remaining mixes did not.

Mix #	Aggregate (lb/yd ³)			Cement (lb/yd ³)	Water (lb/yd ³)	Air-entraining agent (oz)		Average ² unit weight (lb/ft ³)	Average ² 28-day strength (psi)
	bottom ash	sand ¹	fly ash			DaraFill™	DX II™		
1	1474			75	880		64	86	11
2	1423			100	975		91	86	14
3	1390			150	934		183	85	28
4	1391			150	818	62		75	13
5	1358			200	880		456	82	39
6	1069			200	705	64		84	84
7	1121			400	791		546	85	153
8	1150			400	678	60		80	162
9		(w) 2600		100	400		10	110	34
10		(w) 2160		100	400	3		113	59
11		(f) 2500		100	400		10	105	29
12		(f) 2080		100	400	3		99	34
13		(w) 2560		150	400		10	111	80
14		(w) 2518		200	400	3		118	185
15		(w) 2080		200	400		10	120	201
16		(f) 2420		200	400		10	106	272
17		(w) 2480	150	50	400		10	118	48
18		(f) 2385	150	50	400		10	114	26
19		(w) 2050	100	100	400	3		109	72
20		(w) 2230	100	100	500		10	121	473
21		(w) 2380	200	100	400		10	124	188
22		(w) 1945	200	100	400	3		117	178
23		(w) 1910	400	100	500		10	132	1137
24		(f) 1835	400	100	500		10	102	770

¹(w) = washed concrete sand; (f) = unwashed fill sand

²Average of three cylinders/strength tests

c. Comments by Contractor. The contractor documented several comments after preparing the mix designs. Some of the comments may be applicable to the industry as a whole. Others represent concerns that are specific to the operation and geographic region of the contractor. They are presented here as a single example of what a user of this ETL may encounter when working with a contractor. The comments are listed according to the aggregate used.

Comments regarding bottom ash mix designs (Mix #s 1-8):

"There are quite a few problems with using bottom ash as an aggregate for flowable fill. Bottom ash is a waste material; we would not even be willing to load it into the batch plant for fear of getting it mixed into other aggregates and contaminating a concrete mix. A separate batch plant to load and weigh the bottom ash would be required."

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"The water demand is very, very high, around 100 gallons per cubic yard. This would present a problem in hauling material to a job site. You would have to put most of the water in the load at the batch plant; you would not have enough water on the truck to add it on site. Therefore you would have to cut back on your load size, which would increase your costs."

"The air-entraining agent demand is very high, about 46 times that of CLSM using sand as the aggregate. Without air the mix lack cohesiveness, water migrates to the top immediately, and the material does not flow well at all. As soon as it stops moving it settles right in and does not move at all. Adding these high doses of air-entraining agent is very costly. If good flowability is not required and segregating material will not be a problem you could use this product in those applications."

Comments regarding sand mix designs (Mix #s 9-16):

"A mix out of this group is what we would normally supply to a job. A mix using washed sand, cement and Darex II™ would be the least disruptive for us to supply. These materials are always in our batch plant."

"You can use a non-ASTM material such as sand fill which we have done in the past, but you take the risk of contaminating other aggregates. Depending on the type of material you may have trouble getting it out of the bin. We had to use a bin vibrator and in some cases shovel non-standard material down through the batch plant, which can be dangerous."

"The water demand is a little higher than normal concrete, but not too high to cause problems with batching or mixing."

"By putting in 5-10 times the normal dosage rate of air-entraining agent (Darex II™), you can achieve 15-20% air content, this is economical ... By using DaraFill™ you can increase your load size because you do not need to haul the mix as wet. DaraFill™ gives you water reduction and higher air contents (25%)."

Comments regarding sand and fly ash mix designs (Mix #s 17-24):

"Fly ash has not been readily available in our area until recently."

"A lot of our batch plants are equipped with only one silo which makes it impossible to use fly ash."

"Fly ash is cheaper than cement but the material we are using now comes from a distant source and trucking is expensive."

"Fly ash increases the air-entraining agent demand, about 3-5 times the normal dosage rate (Darex II™). Fly ash does decrease the water demand but in CLSM it is not that great a benefit."

"There are some low quality fly ashes that cannot be used in concrete that would probably work well in CLSM, but contamination would again be an issue."

d. General Comments. Users of this ETL are encouraged to view the above trial mix designs and contractor comments as a single, baseline example of the use of the Example Specification of the previous section. The mix designs themselves are neither encouraged nor discouraged. However, the underlying process used to develop these designs, based upon the suggestion in

ACI 229R-94 that the suitability of a non-standard aggregate should be tested in a CLSM mixture to determine whether it meets specified requirements, is encouraged.

Use of non-standard, discarded, or recycled materials in CLSM is a rapidly evolving area. Broadening industry experience in this area and improvements in mix designs incorporating such materials are expected.

6. Reference Standards, Specifications and Documents.

American Concrete Institute

- 304 Guide for Measuring, Mixing, Transporting and Placing Concrete
- 116R Cement and Concrete Terminology (Report)
- 229R Controlled Low Strength Materials (CLSM) (Report)

ASTM

- C 94 Standard Specifications for Ready-Mixed Concrete
- C 150 Standard Specification for Portland Cement
- C 494 Standard Specification for Chemical Admixtures for Concrete
- C 618 Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
- D 4832 Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM)
- D 5971 Standard Practice for Sampling Freshly Mixed Controlled Low Strength Material.
- D 6023 Standard Test Method for Unit Weight, Yield, Cement Content, Air Content (Gravimetric) of Controlled Low Strength Material (CLSM)
- D 6024 Standard Test Method for Ball Drop on Controlled Low Strength Material (CLSM) to Determine Suitability for Load Application
- D 6103 Standard Test for Flow Consistency of Controlled Low Strength Material (CLSM)

New York State Department of Transportation, Geotechnical Engineering Bureau, Special Specification Item 17203.80, Controlled Low Strength Material, 1996.

Transportation Research News. Transportation Research Board, National Research Council. No. 184. May-June, 1996.